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The Association between Mandated Preseason Heat Acclimatization Guidelines and Exertional Heat Illness during Preseason High School American Football Practices

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Background: The risk of heat-related illness and death may continue to increase in many locations as a consequence of climate change, but information on the effectiveness of policies to protect populations from the adverse effects of excessive heat is limited. In 2009, the National Athletic Trainers' Association Inter-Association Task Force (NATA-IATF) released guidelines to reduce exertional heat illness (EHI) among U.S. high school athletes participating in preseason sports activities, including preseason practice sessions for American football. A subset of state high school athletic associations have implemented state-mandated guidelines consistent with the 2009 NATA-IATF recommendations, but their effectiveness for reducing preseason EHI is unknown.

Objectives: This study examines the association between the enactment of state high school athletic association–mandated NATA-IATF guidelines and the rate of EHI among high school students during preseason American football practice sessions.

Methods: We performed a quasi-experimental interrupted time-series study of EHI during high school American football practices in the 2005/2006–2016/2017 school years. We estimated state-level EHI rates using High School Reporting Information Online injury and athlete-exposure data, and used generalized estimating equations Poisson regression models to estimate incidence rate ratios (IRRs) and 95% confidence intervals (CIs) comparing state-years with and without mandated NATA-IATF guidelines. State-level covariates included state-year–specific average August temperatures, yearly deviations from each state's August average temperature across the study period, and school year.

Results: Data were available for 455 state-years from 48 states, including 32 state-years (7.0%) from 8 states when mandated guidelines consistent with the NATA-IATF recommendations were implemented. During an estimated 2,697,089 athlete-exposures, 190 EHIs were reported. Estimated preseason EHI rates were lower during state-years with versus without mandated guidelines (adjusted IRR = 0.45, 95% CI: 0.23, 0.87).

Conclusions: Our findings suggest that high school athletes would benefit from enactment of the 2009 NATA-IATF guidelines. Similar analyses of the effectiveness of other public health policies to reduce adverse health effects from ambient heat are warranted. https://doi.org/10.1289/EHP4163

Introduction

Heat-related illness encompasses 10 medical conditions involving environmental heat, including heat stroke, heat syncope, heat exhaustion, and heat edema (Armstrong 2003; WHO 2018; Weiner and Horne 1958). Heat stroke can be further refined to classic heat stroke and exertional heat stroke, which are both caused by a failure of the body's thermoregulatory system. However, whereas classic heat stroke typically involves infants, young children, and elderly populations exposed to extreme environmental heat (e.g., summer heat waves), exertional heat stroke is caused by a combination of environmental heat and metabolically produced body heat (Casa and Armstrong 2003; Casa et al. 2015; Leon and Bouchama 2015; Yeo 2004). The risk of all forms of heat-related illness and death is likely to increase as a consequence of climate change (Pachauri et al. 2014), which supports the need to implement and evaluate policies to protect populations from the adverse effects of excessive heat.

Within sports medicine, heat-related illness is discussed in the context of exertional heat illness (EHI) events, which include conditions ranging from heat cramps to exertional heat stroke (Casa et al. 2015). Exertional heat stroke, the most severe type of EHI, can result in permanent disability or death if not quickly identified and treated (Binkley et al. 2002; Casa et al. 2012a, 2015).

Approximately 9,000 EHI events are treated annually (CDC 2010) among nearly 8 million student-athletes who participate in U.S. high school sports (National Federation of State High School Associations 2017). Although EHI can affect students participating in all high school sports (Kerr et al. 2013a), they occur most often in association with American football (CDC 2010; Kerr et al. 2013a; Nelson et al. 2011). During the 2005/2006–2010/2011 school years, the EHI rate in American football was higher than that of all other high school sports combined (Kerr et al. 2013a). Moreover, 83% of all EHI events during school-sanctioned high school football activities occurred during the preseason activities (Yeargin et al. 2016) that typically occur in late summer before the first in-season competition and include formal team practices and scrimmages.

In 2009, the National Athletic Trainers' Association Inter-Association Task Force (NATA-IATF) released preseason heat "acclimatization" guidelines (hereafter, NATA-IATF guidelines) (Casa et al. 2009). These guidelines aimed to reduce the risk of EHI among all high school athletes participating in preseason sports activities by promoting gradual acclimatization during the first 2 weeks of the preseason, where the term acclimatization refers to short-term physiological adaptations to high ambient

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temperatures and humidity during this period (Armstrong and Maresh 1991). In this study, we refer to these recommendations as acclimatization guidelines; however, we note that the 2-week period is not sufficient to ensure complete physiological adaptation to high-exertion activities during very hot temperatures. Specific recommendations concern the length of practice periods and rest breaks, and limitations on double-practice days. In addition, an athletic trainer must be present at all practices and must have the authority to cancel or delay practice because of inclement weather or heat. Additional recommendations specific to American football concern the types of practice contact drills and equipment worn during preseason practices.

The NATA-IATF guidelines were based on epidemiologic research, biological, and clinical evidence from laboratory and sideline studies and on information provided by content-area experts. However, to our knowledge, the effectiveness of the NATA-IATF guidelines for reducing EHI events has not been investigated. In the United States, high school sport rules and safety are regulated at the state level by state high school athletic associations, and a subset of state high school athletic associations implemented state-mandated guidelines consistent with the NATA-IATF recommendations after they were introduced in 2009 (Adams et al. 2017). For the present study, we used an interrupted time-series design to examine the association between the enactment of state high school athletic association–mandated EHI guidelines (defined as state mandates meeting criteria set forth by the NATA-IATF guidelines) and state-level EHI rates in American football preseason practices during the 2005/2006–2016/2017 school years.

Methods

The NATA-IATF guidelines were released in 2009. Subsequently, individual state high school athletic associations began mandating these guidelines at their own pace. We integrated injury surveillance and EHI implementation data from multiple sources to perform a quasi-experimental time-interrupted series study (Glass 1997) to estimate the effect of state-mandated guidelines consistent with the NATA-IATF preseason heat acclimatization guidelines on the rate of EHI during preseason high school football practices during the 2005/2006–2016/2017 school years. This study was approved by the institutional review board at the University of North Carolina at Chapel Hill. Informed consent was not required because this study used previously collected de-identified data; further, the parent study from which the injury surveillance data were obtained was granted a waiver of the informed consent/assent requirement under the Institutional Review Board Latitude to Approve a Consent Procedure that Alters or Waives Some or All of the Elements of Consent, §46.116, DHHS (U.S. Department of Health and Human Services) 2016.

Data from previous research were used to identify the state-years during 2005/2006–2016/2017 that state high school athletic association–mandated guidelines met NATA-IATF guidelines (Adams et al. 2017). All state-years in the data set were dichotomized as "without NATA-IATF mandate" (for years without state high school athletic association–mandated guidelines that met NATA-IATF criteria) or "with NATA-IATF mandate" (for years with state high school athletic association–mandated guidelines that met NATA-IATF criteria).

Data Collection

Injury and athlete-exposure data for U.S. high school American football from the 2005/2006–2016/2017 school years were provided by the High School Reporting Information Online system (HS RIO). The methodology of HS RIO has been previously described in-depth (CDC 2006; Rechel et al. 2008). In brief, HS RIO collects data from a sample of high schools with at least one NATA-affiliated athletic trainer with a valid email address. For the present study, we used data from two HS RIO data collection panels. The first was a stratified random sample (with eight strata based on enrollment of $\leq$1,000 or $>$1,000 and U.S. Census geographic region) of approximately 100 high schools per year that were recruited annually beginning in the 2005/2006 school year and that reported data for nine sports, including American football. The second was an annual convenience sample of high schools that began in the 2008/2009 school year. We used data from both of the HS RIO panels to maximize the number of state-years and EHI events in the data set. The annual participation of high schools with American football programs varied during the study period, ranging from 95 to 186 schools (with a mean $\pm$ standard deviation of 139 ± 33) from a total of 48 states.

Athletic trainers from participating high schools reported injury incidence and athlete-exposure information weekly throughout the school year using a secure website. For each injury, the athletic trainer completed a detailed injury report with information about the athlete (e.g., age, height, weight), the injury (e.g., site, diagnosis, severity), and the injury event (e.g., activity, mechanism). Diagnoses were limited to prespecified options: prior to the 2012/2013 academic year, the only EHI diagnosis available was heat exhaustion/heat stroke, but EHI-related diagnoses were expanded beginning in 2012/2013 to include heat syncope, heat exhaustion, heat stroke, heat cramps, and other heat illness. All athletic trainers who contributed to HS RIO were NATA-affiliated, and prior research has suggested that athletic trainers successfully diagnose diverse orthopedic injuries in high concordance with physicians (Lombardi et al. 2016). Further, the NATA provides EHI guidelines and executive summaries, which explicitly outline the diagnostic criteria for each condition (e.g., Casa et al. 2015). Thus, the definition of EHI for the study was all events reported to HS RIO that *a*) were classified by the reporting athletic trainer as heat-related, *b*) occurred as a result of participation in a high school-sanctioned American football preseason practice, and *c*) required medical attention by an athletic trainer or physician.

Participating athletic trainers also collected athlete-exposure data, with one athlete-exposure defined as one athlete's participation in one school-sanctioned practice or competition. For example, a practice that had 75 players participating would yield 75 athlete-exposures; if these 75 players all participated in 10 practices, the summed athlete-exposure count would be 750 (i.e., 75×10). HS RIO does not stratify practice athlete-exposures by time in season (e.g., preseason). Therefore, we estimated the proportion of preseason athlete-exposures based on data from the High School National Athletic Treatment, Injury and Outcomes Network surveillance program, which indicated that 40.5% of practice athlete-exposures for high school football occurred during the preseason in 2011/2012–2013/2014 (Dompier et al. 2015). We applied this proportion (40.5%) to the total practice athlete-exposure count in HS RIO to estimate preseason practice athlete-exposure counts (e.g., 200,000 practice athlete-exposures $\times 0.405 = 81{,}000$ preseason practice athlete-exposures). EHI rates in American football preseason practices were estimated as the summed number of EHI divided by the summed number of athlete-exposures and are presented per 10,000 athlete-exposures (e.g., 10 EHI and 100,000 athlete-exposures would yield an EHI rate of 10/100,000, or 1/10,000 athlete-exposures).

Statistical Analyses

We used generalized estimating equation (GEE) Poisson regression models, with correction for overdispersion using the Pearson's chi-squared statistic, to estimate adjusted EHI incidence rate

ratios (IRRs) comparing EHI rates between state-years with and without NATA-IATF mandates. Because not all states are represented by HS RIO, we restricted analyses to only those states and years with available injury and exposure data (455 state-years from 48 states). We adjusted for state-level covariates in all models to control for potential confounding, including the overall average August temperature in each state during 2005/2006–2016/2017, and the yearly deviation of each state's annual average August temperature from the overall average. Temperature data originated from the National Oceanic and Atmospheric Administration's National Centers for Environmental Information (2016). In addition, we adjusted for school year to control for temporal trends in EHI incidence and/or reporting. All covariates were modeled as simple continuous variables after exploratory analyses indicted comparable effect estimates when school year and average August temperature variables were modeled using linear, quadratic, and cubic terms and when school year was modeled using linear splines (see Table S1).

We also conducted sensitivity analyses to account for partial compliance with NATA-IATF guidelines and potential lagged effects of state guidelines, consistent with previous research (Kerr et al. 2013b) To account for partial compliance, we subdivided the "without NATA-IATF mandate" exposure category to include a third "partial NATA-IATF mandate" category for state-years with state mandates that either met at least one NATA-IATF criterion, or state-years with states recommending (as opposed to requiring) the implementation of best-practice standards (e.g., they used wording such as "should" instead of "must"). We used three different approaches to evaluate lagged or early effects. First, we reclassified the first year in which an NATA-IATF–consistent state mandate was implemented as a "without mandate" state-year, assuming a 1-y lag in the potential effect of a newly implemented mandate on EHI. Second, we evaluated two gradual transition scenarios by modeling a three-category state-year exposure variable coded as 0 for "without mandate" years, 0.5 for the first year of a mandate, and 1 for subsequent state-years after implementation as well as a four-category variable with the first and second years after a mandate was implemented coded as 0.33 and 0.67, respectively. Finally, we reclassified the year prior to formal mandate implementation classified as a "with mandate" state-year, under the assumption that compliance may already have begun in the previous year.

Results

In total, 190 EHIs were reported during an estimated 2,697,089 American football preseason practice athlete-exposures, resulting in an EHI rate of 0.70 per 10,000 athlete-exposures [95% confidence interval (CI): 0.60, 0.80]. None of the 190 EHIs resulted in fatalities. Of the 128 events documented during and after the 2012/2013 academic year (when specific EHI outcomes were first recorded), most were specified as heat exhaustion (68.8%), followed by heat-related cramps (15.6%).

A total of 32 state-years (7.0% of all 455 state-years) in eight states were classified as meeting the NATA-IATF guidelines. During the state-years with mandates, 7 EHI events were reported during an estimated 167,418 preseason football practice athlete-exposures (Table 1), for an EHI rate of 0.42 per 10,000 athlete-exposures (95% CI: 0.11, 0.73). During state-years without mandates, 183 EHI events were reported during approximately 2,529,671 preseason practice athlete-exposures, for an EHI rate of 0.72 per 10,000 athlete-exposures (95% CI: 0.62, 0.83). Controlling for August temperature variations and linear secular trends, the high school American football preseason practice EHI rate was lower in state-years with versus without state high school athletic association–mandated guidelines that met NATA-IATF guidelines (IRR = 0.45, 95% CI: 0.23, 0.87; Table 1). In other words, implementation of a mandated guideline was associated with a 55% reduction in EHI rates (95% CI: 13, 77%).

Table 1. Adjusted incidence rate ratios (IRRs) for exertional heat illness (EHI) during American football preseason practices in states and years with and without enactment of state high school athletic association–mandated guidelines consistent with NATA-IATF recommendations.

Analysis	EHI events (n)	Athlete-exposures (n)[a]	IRR (95% CI)[b]
Primary model[c]			
Without mandate	183	2,529,671	Ref
With mandate	7	167,418	0.45 (0.23, 0.87)
Partial mandates[d]			
Without mandate	90	1,526,164	Ref
Partial mandate	93	1,003,507	0.50 (0.25, 1.00)
With mandate	7	167,418	0.29 (0.12, 0.69)
1-y delay[e]			
Without mandate	184	2,568,244	Ref
With mandate	6	128,845	0.47 (0.23, 0.98)
Gradual enactment in first year[f]			
Without mandate	183	2,529,671	Ref
With mandate	6	128,845	0.44 (0.21, 0.91)
Gradual enactment in first 2 y[g]			
Without mandate	183	2,529,671	Ref
With mandate	5	91,792	0.43 (0.20, 0.91)
Early enactment in previous year[h]			
Without mandate	183	2,499,714	Ref
With mandate	7	197,375	0.38 (0.20, 0.73)

Note: Ref, reference.
[a]Each athlete-exposure represents participation in a single preseason practice activity by a single athlete. The proportion of all school-sanctioned high school football practices or competitions during the preseason was estimated as 0.405 (Dompier et al. 2015).
[b]IRRs are adjusted for school year, state average August temperature, and deviation of annual average August temperature from the state average during 2005/2006–2016/2017.
[c]IRR for EHI rate during state-years with vs. without NATA-IATF–compliant mandated guidelines.
[d]Partial mandate state-years were not fully compliant with NATA-IATF guidelines but met at least one criterion or had a comprehensive plan that lacked best-practice wording.
[e]The first state-year following implementation of NATA-IATF–compliant mandated guidelines was reclassified as a "without mandate" year.
[f]Guideline variable coded as 0 for "without mandate" years, 0.5 for the first state-year following implementation of NATA-IATF–compliant mandated guidelines, and 1 for subsequent state-years. There was 1 EHI/38,573 athlete-exposures during state-years in the first year following implementation.
[g]Guideline variable coded as 0 for "without mandate" years, 0.33 and 0.67 for the first and second state-year following implementation of NATA-IATF–compliant mandated guidelines, respectively, and 1 for subsequent state-years. There were 2 EHI/75,626 athlete-exposures during state-years in the first 2 years following implementation.
[h]The state-year prior to implementation of NATA-IATF–compliant mandated guidelines was reclassified as a "with mandate" year.

Sensitivity analyses were conducted for the five additional scenarios previously described (Table 1). When state-years in partial compliance with NATA-IATF guidelines were evaluated as a separate group, 145 state-years, 93 EHI events, and 1,003,507 athlete-exposures were reclassified from the "without mandate" to the "partial mandate" group, resulting in an adjusted IRR = 0.50, (95% CI: 0.25, 1.00) for EHI during state-years with partial mandates versus without mandates (50% reduction, 95% CI: 0.1, 75%), and an adjusted IRR = 0.29 (95% CI: 0.12, 0.69) for EHI in state-years with mandates versus without mandates (71% reduction, 95% CI: 31, 88%). Although the EHI rate was lower in the "with mandate" group than the "partial mandate" group, the difference was not statistically significant (IRR = 0.57, 95% CI: 0.30, 1.10). Adjusted IRRs comparing EHI rates during state-years with versus without mandates were similar to the primary model IRR for sensitivity analyses of delayed, gradual, and early enactment of state guidelines (IRRs of 0.38–0.47) (Table 1).

Discussion

This project is one of the first to evaluate heat illness–related prevention guidelines. EHI rates from U.S. high school American

football preseason practices were lower during state-years with versus without state high school athletic association–mandated heat acclimatization guidelines that met the NATA-IATF criteria. Our findings highlight the potential value of state-level mandated guidelines to reduce the incidence of heat-related illness in high school athletes. Further, they provide additional support for public health guidelines and policies to protect highly exposed or vulnerable populations from adverse effects of excessive heat, including workers engaged in physically demanding outdoor work (Martínez-Solanas et al. 2018) and the elderly (Gronlund et al. 2014).

The NATA-IATF guidelines were one of the first of several recent position statements and best-practice guidelines related to EHI that aimed to modify risk factors prevalent in athletic games and practices in high school (Casa et al. 2009, 2012b, 2013, 2015; Herring et al. 2012; McDermott et al. 2017; Expert Panel 2016). The NATA-IATF guidelines limit practices to 3 h, which is consistent with epidemiologic studies highlighting that over one-third of all EHI occur after 2 h of practice (Kerr et al. 2013a) and that the risk of EHI is almost 10 times higher when August practices are more than 3 h long (Tripp et al. 2015). The guidelines also eliminate double-practice days during the first week of preseason to allow athletes to acclimatize to exercise and heat, consistent with evidence showing increased EHI rates on double-practice days, compared with single-practice days (Cooper et al. 2016). The NATA-IATF guidelines focus on the first 2 weeks of the preseason when 95% of heat acclimation adaptations occur (Armstrong and Maresh 1991). Specifically, repeated exercise in hot, humid conditions causes sodium retention and expanded plasma volume, which increases stroke volume, decreases heart rate, and increases sweat rate and sweat sensitivity (Armstrong and Maresh 1991; Nielsen et al. 1993; Roberts et al. 1977). These adaptations improve performance (Chalmers et al. 2014) and increase heat dissipation, thus reducing the risk of elevated core body temperature and EHI during exercise (Armstrong and Maresh 1991).

Evidence of Reduced EHI

We found evidence of reduced EHI during state-years with partial compliance versus no compliance in a sensitivity analysis. Sensitivity analyses of the potential influence of delayed or early implementation of guidelines did not indicate substantial differences in EHI from analyses that assumed full implementation in the first year that the mandates were enacted. Further research is needed to evaluate the influence of specific components of the guidelines. Also, previous research on the effectiveness of interventions to reduce sports-related injuries has highlighted the need for both outcome evaluation (i.e., of the intervention's effectiveness in producing change) and process evaluation (e.g., to identify factors that promote or inhibit implementation) (Finch 2006). A previous survey of 1,142 certified athletic trainers found that in the 2011 preseason, high school football programs complied with only 10.4 of the 17 guidelines on average, and only 2.5% of programs were fully compliant with all 17 guidelines (Kerr et al. 2014). However, compared with programs from states without mandates, programs in states with mandates were more likely to comply with more guidelines and to be fully compliant with all 17 guidelines (partial compliance was not examined) (Kerr et al. 2014). Additional studies are also needed to identify state and local high school factors associated with enactment of the NATA-IATF guidelines, including factors that facilitate adoption at the state level and increase the capacity for implementation at the local high school level.

These findings also support ongoing surveillance to continue monitoring trends in the incidence of EHI events and EHI-related fatalities to determine the potential sustainability of the benefits incurred from EHI prevention strategies. Sports injury surveillance systems, such as the HS RIO utilized in the present study, facilitate large-scale cross-sectional (Collins et al. 2014; Kerr et al. 2015, 2016) and longitudinal (Lincoln et al. 2007; Yang et al. 2017) studies of the effectiveness of injury prevention interventions. This type of research is needed to develop strategies for successful and widespread implementation of policies and programs that reduce EHI rates and other causes of injury and death among high school athletes.

Strengths and Limitations

This quasi-experimental interrupted time-series study combined three state-level data sources to examine population-level impacts of state-level EHI prevention policies during high school American football preseason practices across 12 academic years. HS RIO surveillance data rely upon athletic trainers to document EHI and athlete-exposures. A recent study reported 92% agreement between injury diagnoses by athletic trainers and physicians (Lombardi et al. 2016). Another limitation was the small number of EHI ($n = 190$), despite the use of a larger sample than previous studies of high school American football preseason practices (e.g., Kerr et al. 2013a; Yeargin et al. 2016), which limited precision and our ability to adjust for covariates. Also, we could not assess the compliance of individual schools with the NATA-IATF guidelines or the specific policies associated with reductions in EHI rates. In addition, state-level annual average August temperatures may not be representative of local temperatures, particularly in states with wide ranges of climates, and they may not reflect in-venue temperatures and the effects of daily temperature fluctuations, playing surfaces, and other factors. Although HS RIO provides data from a large sample of high schools, data from high schools with athletic trainers who participate in HS RIO may not be generalizable to nonparticipating high schools with athletic trainers or to high schools without athletic trainers or sufficient athletic resources. An estimated 30% of U.S. public high schools do not have access to athletic trainers, and larger schools are more likely to have access than smaller schools (Pryor et al. 2015). An additional study with public and private high school athletic directors noted budgetary constraints as a barrier to hiring an athletic trainer (Pike et al. 2017). The composition of states participating in HS RIO in any given year is variable and data were available for only 74% (455/612) of possible state-years (50 states and Washington DC $\times$ 12 school years). Finally, athlete-exposures are not time-based, and thus we were not able to account for the length of each practice or the time of day when practices occurred. Finally, because HS RIO does not stratify athlete-exposures by time in season, we had to estimate the proportion of athlete-exposures that occurred during the preseason based on data from another high school sports injury surveillance system (Dompier et al. 2015) and applied this proportion across all high school American football programs included in the study.

Conclusions

The risk of heat-related illness and death is likely to increase in many locations as a consequence of climate change (Pachauri et al. 2014), and effective policies are needed to protect populations from adverse effects of excessive heat. The present study, in combination with other biological, epidemiologic, and clinical evidence, supports the effectiveness of NATA-IATF guidelines in reducing EHI rates among American high school football players. State high school athletic association–mandated heat acclimatization guidelines that met the NATA-IATF recommendations were

associated with a 55% reduction in the incidence of EHI. Based on our findings, we recommend that state high school athletic associations consider mandating NATA-IATF guidelines for their high schools. However, future studies should continue to monitor trends in EHI rates while examining their hypothesized association with NATA-IATF guideline mandates. Evaluative research should also aim to identify factors that facilitate and impede implementation and adoption of the NATA-IATF guidelines as well as other public health guidelines and policies to reduce the adverse health effects of ambient heat.

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